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Mounding technique improves physiological performance and yield of oil palm on Spodosols

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ABSTRACT

Spodosols have been widely used for oil palm plantations, specifically in Kalimantan, Indonesia. However, they are sub-optimal for agriculture due to a lack of water and nutrient-holding capacity and a spodic layer that limits plant root development. Therefore, proper agriculture practices are needed for oil palm to enhance its potential yield. This study aims to determine the effect of the mounding technique on the physiological performance and yield of oil palms in spodosol. The study location was well-managed, with eight blocks of oil palm plantations planted in 2008 on spodosols (Typic Haplohumod) in Central Kalimantan. The mounding technique was applied to four blocks of oil palm planted in 2015, while the remaining four were left without mounding. The parameters observed were soil moisture, transpiration, number of bunches, bunch weight, and yield. The results showed that the average moisture in the mounded soil was 4% greater than the control. Additionally, the average daily transpiration of oil palm with the mounding was up to 2.30 mm day^{-1} or three times higher than the control. The implication was that the average yield of oil palm increased from approximately 1.84 to 3.71 tons ha^{-1} year^{-1} compared to no-mounding treatments. Furthermore, the average yield was 19-66% higher than the block without the mounding application.

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1. INTRODUCTION

Spodosols are soil formed from quartz sand as the parent material, characterized by an albic horizon and an accumulation of iron, aluminum, and or organic material called a spodic layer (de Menezes et al., 2018; Syuhada et al., 2014). They are widespread in cold, temperate, or wet climates, and most of these soil types are discovered in Russia, Northern Europe, and Canada (Wahjuni et al., 2021). However, this soil type is also quite commonly observed in the tropics. In Indonesia, spodosol covers an area of approximately 2.16 million ha, about 1.1% of the entire territory of the country (Agroklimat, 2000).

Spodosol is a nutrient-poor soil (Adiwiganda et al., 1993; Syuhada et al., 2014). Physically, this soil is not suitable for agriculture because the spodic layer can limit root growth. Hence it is difficult for the root system to penetrate. The texture of sandy soil at its top reduces the ability to retain water and nutrient (Surianto et al., 2015), hence, increasing nutrient leaching and drought stress. This soil type could inhibit oil palm growth due to poor drainage (Safitri et al., 2018). Therefore, spodosol has a low potential for agricultural business. However, with the lack of suitable land, this soil type was widely used as agricultural land (Syarovy et al., 2015). In addition, this soil type is very responsive to the applied cultivation techniques (Leslie et al., 2015). Therefore, if spodosol land management is carried out properly, it is possible to obtain economic cash crop production.

The farmers in Malaysia have used this soil for cash crop farming, such as maize and watermelon. Large-scale coconut plantations have been expanding on the land (Mohd Yusoff et al., 2017). It is also used in Indonesia for oil palm plantations (Syarovy et al., 2015). However, the performance and yield of this crop on spodosols remain less than optimal due to a lack of understanding of agricultural practices. Appropriate agricultural practices are needed to maximize the performance of oil palm plantations on this land. The techniques required to improve the performance of this crop in spodosols include adding soil ameliorants (Santoso et al., 2015), improving the microclimate through cover crops management, and proper fertilization (Syarovy et al., 2015). Furthermore, other studies showed that the production of 8-year-old oil palm plantations in spodosols reaches over 26 tons ha^{-1} following the proper and continuous application of these techniques (Santoso et al., 2013).

One of the keys to optimizing oil palm yield in spodosols is providing sufficient space for root growth. Applying soil amelioration, soil and water conservation, and proper fertilization can significantly affect production when root development is not disturbed. The spodic layer on spodosols should be at least 75 cm for proper growth and development of oil palm roots (Wiratmoko et al., 2015). Furthermore, the shallow spodic layer is one factor that inhibits oil palm root growth at a depth of 0-30 cm (Safitri et al., 2018).

Several techniques have been used to provide space for root development, one of which is breaking the spodic or "hardpan" layer and creating individual big holes. This could increase the yield of oil palm (Surianto, 2016). However, this method is unsuitable when performed on spodosol that has already been cultivated. Based on these conditions, it is necessary to develop other techniques capable of maximizing root growth and be flexibly applied to new and existing oil palm plantations. Therefore, soil mounding, widely applied to peatlands, remains an alternative (Samsuri et al., 2018).

Mounding is a conservation technique in which the soil is placed in the weeding circle of oil palm (Priwiratama et al., 2020). Mounding is applied using soil around plants or mineral soil from other places. This technique can be carried out at all mature oil palm ages. Furthermore, the usual height of the mound is approximately 20-30 cm, and the radius is up to 150 cm. Applying this technique to peat soil using mineral soil is intended to prevent the collapse of oil palm trees. The palm roots tend to appear above the ground when mounding is not applied. However, it enhances root development when being used. It can also help to increase bulk density and oil palm yield (Samsuri et al., 2018). This mounding technique is also often used on oil palm infected by *Ganoderma boninense* so that they do not collapse quickly (Priwiratama et al., 2020).

Information regarding the application of mounding techniques in peat soil using mineral soils have been widely reported (Sakuntaladewi et al., 2022; Wahyudi, 2022). In addition, information regarding the application of this technique to extend the life of oil palm infected by *Ganoderma boninense* has also been extensively studied (Hushiarian et al., 2013; Wong et al., 2021). However, the effects of applying mounding techniques for oil palm plantations on spodosols remain minimal. Therefore, it needs to be further investigations. This study aimed to provide information on soil conditions, physiological performance, and oil palm production in spodosols by applying the mounding technique.

2. MATERIALS AND METHODS

This study was conducted on an oil palm plantation as part of the Wilmar Groups Central Kalimantan Project (CKP), Sampit, Central Kalimantan, Indonesia. The soil type and average temperature are Typic Haplohumod and 27.23°C. Furthermore, the average maximum and minimum temperatures are 32.51°C and 23.55°C, respectively. The site has an average humidity and solar radiation of 82.98% and 17.70 MJ^{-1} $m^{2\ -1}$ day^{-1} (NASA, 2022). It has an average annual equatorial rainfall from 2014 to 4188 mm $year^{-1}$. Additionally, the rainy days are from 114-221 rainy days $year^{-1}$. The months with the highest rainfall are between October and December, while the lowest is between July and September. Pradiko, Ginting, et al. (2016) stated that the Central Kalimantan region is often affected by drought due to the ENSO anomaly.

This study was conducted on eight well-managed blocks of oil palm planted in 2008 (age 14 years). A total of four blocks were used as control blocks without mounding while it was applied to the remaining. As a result, the total control and mounding blocks were 159.38 ha and 127.84 ha, respectively. The technique was applied by digging the soil in the interrow and placing the excavated spodosols on a weeding circle. The mounding has a height of 40 cm with a length and width of 200 cm (Figure 1A). In 2015, the mounding technique was implemented, but in 2019, it was expanded to the remaining four controls because the block subjected to mounding experienced a considerable production boost compared to before the application.

The parameter observed in this study was the blocks' palm yield (tons ha^{-1}) from 2011-2021. Furthermore, the actual transpiration was also observed based on the Heat Ratio Method (HRM) using a sap flow meter (SFM1) provided by ICT International. Sap flow observations were conducted in June 2022 and installed on frond number 17. The transpiration was measured for two days with data acquisition intervals of every 10 minutes. Four sap flow sensors were installed on two randomly selected trees in the mounding blocks (M1 and M2) and two in the non-mounding blocks (C1 and C2). Since the blocks were already mounded when sap flow observation was conducted, physiological performance observations on oil palm trees were performed in the closest block that had not yet been mounded. The process of installing tools, data acquisition, and processing data to produce the actual transpiration value of plants followed the study of Pradiko, Rahutomo, et al. (2022).

Soil moisture was monitored using a soil moisture meter (SMM) MP 406 produced by ICT International. This tool can measure soil moisture continuously based on the volumetric method. Measurement of soil moisture was conducted in June 2022, or almost seven years after treatment. Its measurements were installed on mounding and non-mounding circle weeding with a depth of 15-20 cm. Measurements were carried out for three days with data acquisition intervals every 10 minutes. The observations were located on trees that were installed with sap flow. Furthermore, the same setting was also done for the control block. Figure 1A presents the installation scheme of the SFM1 and SMM tools. Figure 1B shows the condition of the

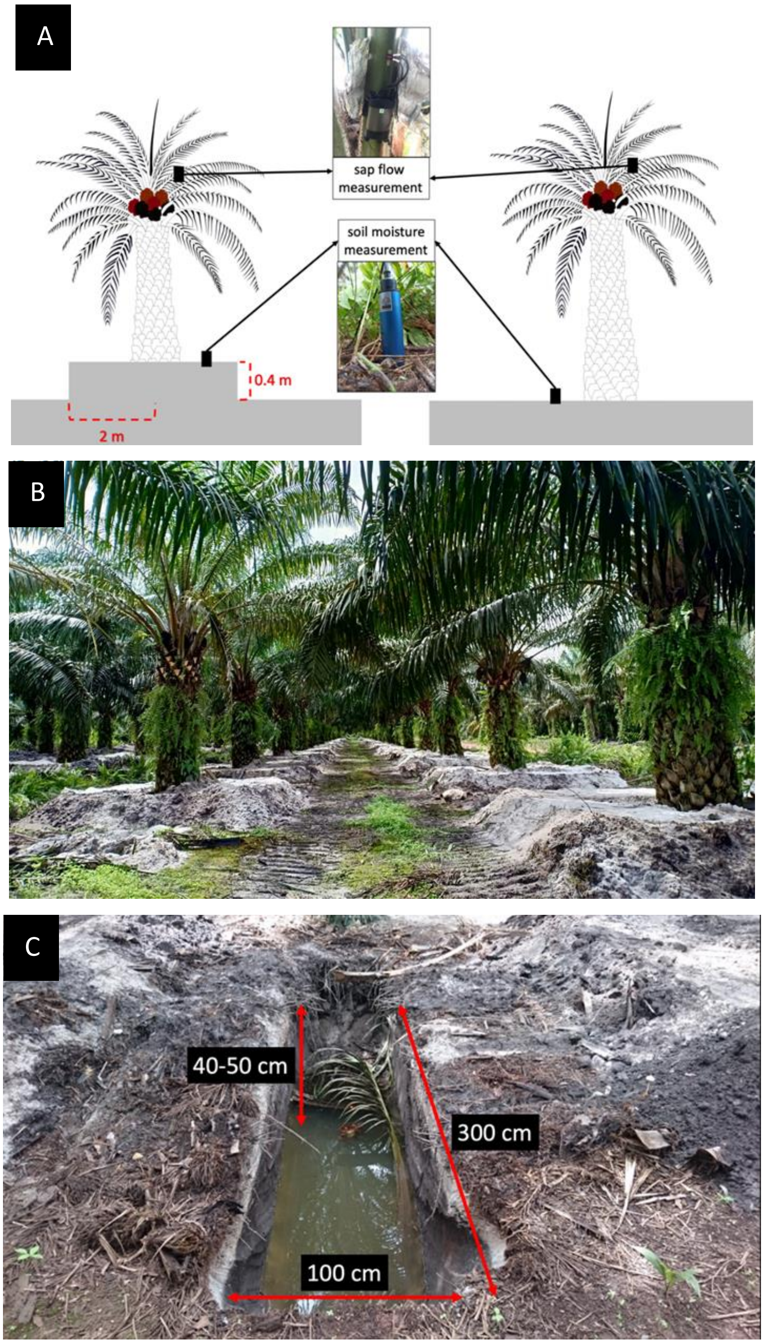

Figure 1. (A) Illustration of sap flow and soil moisture measurement (the oil palm picture modified from (Pradiko, Rahutomo, et al., 2022). The left picture is the measurement of oil palm with mounding application, while the right is the control. (B) Mounding application on an oil palm plantation. (C) Excavated or newly made pit to create mounding eventually became a microsite to accommodate excess water during the rainy season and maintain moisture during the dry season. The pit's dimensions were 300 cm of length, 100 cm of width, and 40-50 cm of depth

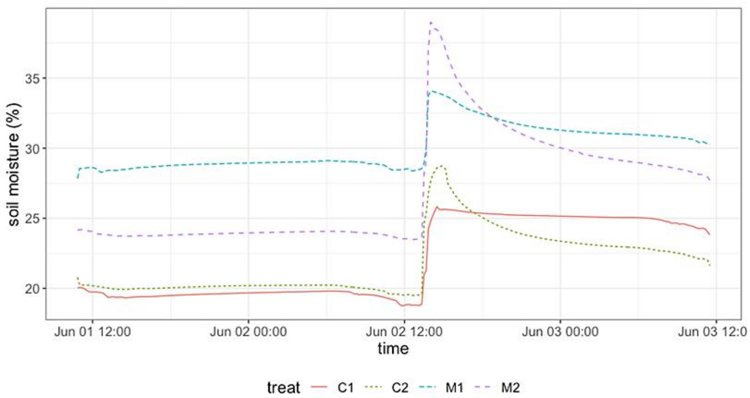

Figure 2. Soil moisture fluctuations in control (C1 and C2) and mounding blocks (M1 and M2)

mounding application. Figure 1C depicts the newly made pit that formed from the mounding creation.

Statistics software R version 4.0.4 and R-studio version 1.4.1106 were used for data analysis and interpretation. Descriptive analysis was conducted to determine the trend of oil palm yield, the diurnal pattern of sap flow, and soil moisture dynamics. The data on productivity, transpiration rate, and soil moisture between the control and mounding blocks were statistically analyzed using a student's t-test (alpha = 10%). However, the productivity analysis was only performed by comparing the data from 2011-2019. Furthermore, a t-test was conducted on the yield difference between mounding and control blocks before and after 2015.

3. RESULT

3.1 Soil Moisture Fluctuation

Figure 2 shows the soil moisture observations in the selected treatments during June 2022. Soil moisture was higher with mounding. Soil moisture in mounding soil was 5-10% higher than in control. The drastic increase that occurred on June 2, 2022, was due to rain. After that, soil moisture tended to decrease. The decrease in soil moisture to the initial position was probably different due to differences in soil texture composition. The increase in soil moisture during observation after June 2022 at 12.00 was due to rain. The results of the t-test (Figure 5A) showed that the soil moisture with and without mounding treatment was significantly different. The average moisture in mounding soil was more than 27%, while in soil without mounding was only about 23%. Therefore, it indicated that the treatment could increase soil moisture.

3.2 Transpiration Rate Dynamic

Figure 3 shows the sap flow observation. The plants with mounding had a higher sap flow rate. The sap flow of oil palms with mounding soil (M1 and M2) was higher than palms without mounding, especially during the day. The sap flow generally increased after sunrise (06:00 local time) and decreased before 15:00 local time. From 15:00 to 06:00 local time, the sap flow rate decreased and approached zero. The maximum value of sap flow in the M1 and M2 treatments were 516.79 and 472.96 cm^3 $hour^{-1}$, respectively. The sap flow rate increased and peaked during the day when solar radiation and air temperature conditions were higher while the humidity was lower. Meanwhile, the maximum value of sap flow in treatments C1 and C2 was 376.26 and 386.16 cm^3 $hour^{-1}$, respectively. The maximum value of sap flow was generally observed at 10:00 to 12:00 local time or near midday. The average sap flow at night and during the day in oil palm with mounding was 97.66 cm^3 $hour^{-1}$, while in oil palm without mounding was only 80.03 cm^3 $hour^{-1}$. The t-test analysis results also showed a significant difference between the palms with and without mounding (Figure 5C).

Figure 5D presents the actual transpiration estimation. The actual transpiration was obtained by multiplying the sap flow with the petiole area and the number of fronds. The transpiration rate of oil palm with mounding treatment was between 1.56-2.30 mm day^{-1}. Meanwhile, the transpiration in the control treatment was approximately three times lower than mounding, which ranged from 0.80-0.86 mm day^{-1}. It is because of the high content of soil moisture that it contains in the mounding treatment. Finally, it supports that besides climatic conditions, soil moisture also strongly influences the transpiration of oil palm.

3.3 Oil palm yield

Figure 4 presents the yield data, the average number of bunches, and the weight of bunches. In general, the number of bunches decreased with the age of the palm. Meanwhile, the average weight of bunches increased with increasing oil palm age. Before the application of mounding in 2015, the productivity of the mounded blocks tended to be lower than the control. However, a higher productivity increase was experienced after mounding than the control.

There was a significant increase in production that occurred two years after the treatment. This lag exists because oil palm, specifically the roots, adapted to the new environmental conditions. Moreover, the increase in plant productivity in the mounding treatment was due to a significant increase in the number of bunches. It showed that the application of mounding could overcome stress on oil palm, especially in critical phase I, namely during sex determination, which occurred about two years before the bunches were harvested. Finally, statistical analysis showed that the treatment of spodosols had a significant effect on oil palm yields (Figure 5B). Figure 5B shows each treatment's average yield increment data for 2011-2015 (before 2015) and 2016-2019 (after 2015). The average yield of oil palms with mounding increased by 11.15 tons FFB (fresh fruit bunch) ha^{-1}, while that of oil palms without mounding increased by 6.64 tons FFB ha^{-1}. After mounding application, oil palms experienced an increase of 1.84-3.71 tons FFB ha^{-1} $year^{-1}$ (with a mean of 2.79 tons FFB ha^{-1} $year^{-1}$). Meanwhile, oil palms without mounding experienced an increase in yield of 1.04-2.22 tons FFB ha^{-1} $year^{-1}$ (with an average of 1.66 tons FFB ha^{-1} $year^{-1}$).

4. DISCUSSION

The mounding technique was proven to be able to improve the level of soil moisture. Soil moisture was one of the factors that affected the root development (Haniff et al., 2014; Intara et al., 2018; Zhang et al., 2019). The root density is directly proportional to the soil moisture. The previous study showed that oil palm's secondary and tertiary roots were more likely discovered in a radius of >150 cm, indicating higher soil moisture (Pradiko et al., 2020; Pradiko, Hidayat, et al., 2016). In this study, moisture in mounding soil was higher than in the soil without mounding (Figure 5A). The implication is that the distribution of roots in the mounding area will be greater than without mounding. The results of the preliminary study (data not shown) indicated that the mounding application could increase the distribution of the total roots up to 14 times. It was in line with a previous study that stated application of mounding on saplings of Norway spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) produced a deeper root system (Celma et al., 2019).

The newly made pit (Figure 1C) that formed to create the mounding in the interrow can accommodate excess water in the rainy season and maintain soil moisture during the dry season.

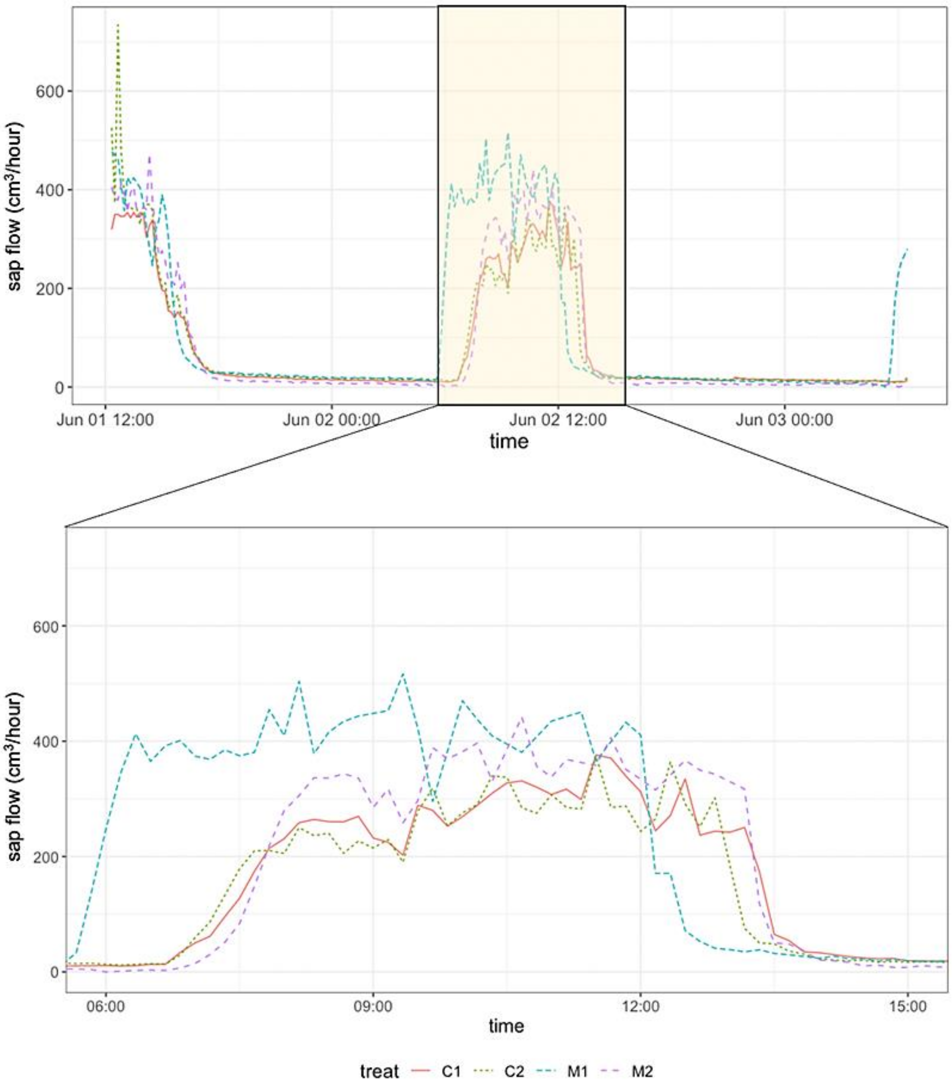

Figure 3. Variation in sap flow rate in the control blocks (C1 and C2) and mounding (M1 and M2). It peaked during the day and then declined to near zero in the evening until late in the morning

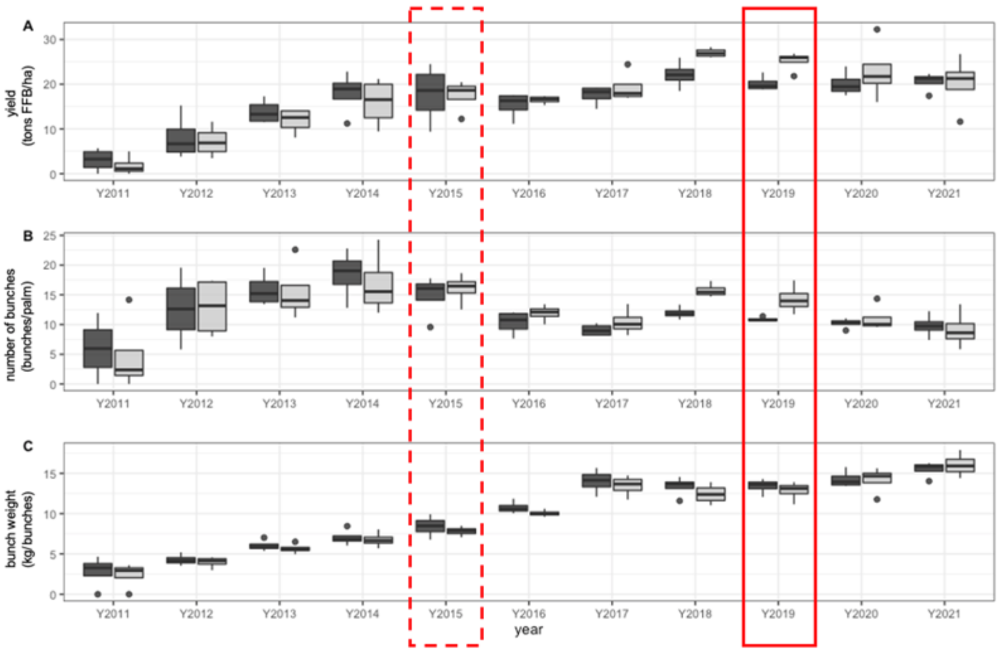

Figure 4. Yield (A), the average number of bunches (B), and average bunch weight (C) of oil palm on control blocks (black boxplot) and mounding (grey boxplot) for the period 2011-2021. The application of mounding on the mounding blocks was marked by an extensive-dotted line, while a line marked mounding application on the control blocks

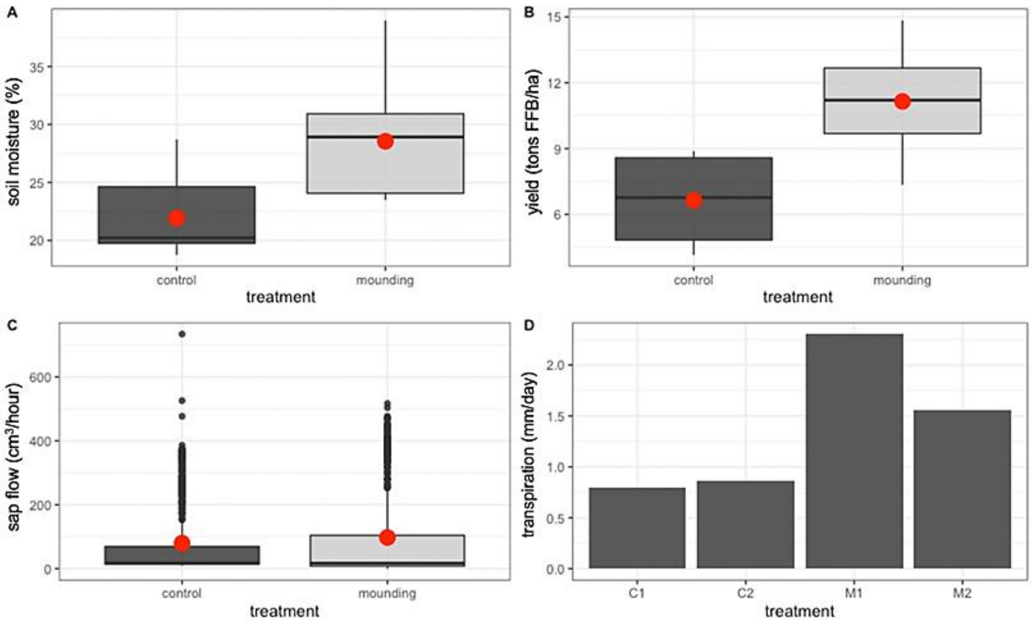

Figure 5. T-test results on the effect of mounding (grey boxplot) and no mounding (black boxplot) on soil moisture (A), yield increment (B), and sap flow rate (C). The transpiration rate in control and mounding blocks was presented in D. The red dot indicates the mean value. Different letters in the boxplot indicate a significant effect on the mounding treatment at a significant level of 10%.

It was following the previous study by Celma et al. (2019). As a result, the pits increased the soil water content (Bohluli et al., 2012). The newly made pit could also reduce nutrient loss due to surface runoff and erosion (Masnang et al., 2022).

Mounding (Figure 1A and 1B) provided additional space for roots to grow. Safitri et al. (2018) stated that the oil palm root in spodosols could not develop properly because of a shallow spodic layer. The addition of approximately 40 cm of mounding soil creates space for the root to grow (Figure 1A). For example, the plant roots have a total of 70 cm of space to grow when the mean spodic later is 30 cm. Proper root growth and development increases plants' chances of uptaking nutrients and water (Intara et al., 2018).

The sap flow rate was influenced by several climatic factors and soil moisture (Pradiko, Rahutomo, et al., 2022). The mounded oil palm had higher sap flow rates during the day because they were supported by higher soil moisture (Figure 5C). This implied that the transpiration rate of these palms would be higher. The availability of water strongly impacts the transpiration rate of oil palms. Brum et al. (2021) stated that oil palm with a sufficient water supply during the dry season would have a higher transpiration rate.

The transpiration rate of oil palm with mounding ranges from 1.5-2.3 mm day^{-1} (Figure 5D). It is higher than a 5-year-old oil palm, which is about 0.46 mm day^{-1} (Pradiko, Darlan, et al., 2022), 1.15 mm day^{-1} in 5-year-old palms in Colombia (Bayona-Rodríguez & Romero, 2016), and 0.82-1.66 mm $days^{-1}$ in 14-year-old palms (Pradiko, Rahutomo, et al., 2022). A higher transpiration rate will increase the rate of photosynthesis. Therefore, the photosynthesis rate influences oil palm production. Romero et al. (2022) stated that crop production depends on the photosynthetic performance of the canopy.

Oil palm productivity in the study blocks was in a phase of a significant increment (Figure 4A), which occurs between 9-16 years old. In some cases, the increase in production began to plateau and tended to decline before reaching the age of 16 (Kome & Tabi, 2019). However, in 2016 and 2017, there was a decrease in production. The prolonged drought due to El Niño caused a decline in production in the observation blocks (Darlan et al., 2016). It was slightly higher in the mounding block because the palms also adjusted to environmental conditions. However, in subsequent drought stress cases, namely in 2018 and 2019, the mounding treatment had a yield and an average number of bunches much higher than the control block (Figure 4B). These differences indicated that mounding could reduce stress on oil palm during critical phases, especially in 6-24 months before bunches were harvested (Woittiez et al., 2017). Therefore, more bunches could be developed and harvested than plants in the control block.

Based on the explanation above, the mounding technique improved soil moisture (Figure 2) and increased oil palm transpiration rate (Figure 5D) and production (Figure 4C). However, it would be better to combine the treatment with organic materials, such as Empty Fruit Bunch (EFB) which could increase the root growth (Santoso et al., 2019). The techniques need to be combined with cover crop management to reduce the erosion rate (Fuady et al., 2019), help maintain soil moisture, and the litter can enrich soil organic matter (Ariyanti et al., 2016).

5. CONCLUSION

Applying the mounding technique on oil palm planted in spodosols could increase soil moisture by up to 10% compared to without mounding. The oil palm absorbed excess soil moisture to increase the rate of transpiration. The oil palm transpiration with mounding treatment was three times higher than without mounding. The oil palm with mounding minimized the effects of drought stress, so the number of bunches produced was much higher than plants without mounding. As a result, the oil palm yield was more significant than it would have been without mounding. It has been demonstrated that mounding improved the ecophysiological conditions of oil palm in spodosols.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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